# DEVELOPMENT OF JUTE AND OKRA FIBRE-BASED NEW COMPOSITE MATERIAL FOR AUTOMOTIVE BUMPER BEAM APPLICATION

Synopsis of the PhD Thesis


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## 1. ABSTRACT

Natural fibers are increasingly used in automotive interior and exterior components. The growing demand for lightweight and environmentally sustainable materials in the automotive industry has led to increased interest in natural fiber-reinforced composites. This study focuses on the development and characterization of a novel composite material reinforced with jute and okra fibers in a polymer matrix, intended for application in automotive bumper beam systems. The research aims to evaluate tensile, impact, flexural, and moisture absorption properties of the composite and compare its performance to that of conventional synthetic materials.

Okra fiber was extracted from locally cultivated okra plants. These fibers represent an underutilized agricultural byproduct with significant economic and environmental potential. India, the world's largest producer of okra, large volumes of okra plant stems are discarded annually as agricultural waste, despite being a rich source of natural fiber suitable for various textile and industrial uses. Although okra fiber is relatively new in composite applications, it exhibits favorable characteristics such as high cellulose content, low density, and good tensile strength. Its distinctive microstructure also enhances energy absorption and impact resistance, which are crucial for automotive bumper applications.

To assess the viability of okra fiber as a reinforcement material, its properties and composite performance were compared with those of traditional jute fiber. Both fibers underwent alkali treatment to improve interfacial bonding with the polymer matrix. Jute fiber, known for its high tensile strength, stiffness, availability, and biodegradability, served as a benchmark material for evaluating strength, rigidity, and sustainability.

Composite samples with varying fiber length and weight fractions were fabricated using a compression molding technique. Mechanical testing covering tensile, flexural, impact, and moisture absorption behavior was conducted in accordance with ASTM standards. Results indicated that okra fiber-reinforced composites offered competitive mechanical performance, particularly in terms of energy absorption and strength, while also achieving weight reduction compared to jute composites and conventional bumper beam materials.

Overall, the study demonstrates that okra fiber-reinforced composites offer a promising, eco-friendly, and cost-effective alternative for non-structural automotive applications. Further research into long-term durability, environmental resistance, and crash performance is recommended to support future industrial use.

## 2. INTRODUCTION

The global automotive industry is undergoing a major shift toward sustainability and environmental responsibility. One key area of innovation is the development of lightweight and environmentally friendly materials to replace conventional, non-renewable materials in vehicle components. Natural fiber-reinforced polymer composites (NFRPCs) have emerged as a promising alternative due to their biodegradability, renewability, low density, and favorable mechanical properties (Mohanty et al., 2005). The integration of such composites in automotive applications not only reduces the overall vehicle weight contributing to improved fuel efficiency and reduced carbon emissions, but also aligns with global sustainability goals.

Natural fibers such as jute, flax, hemp, and sisal have been widely studied and applied in automotive components like door panels, dashboards, and interior linings (Wambua et al., 2003). Among these, jute fiber is particularly attractive due to its high tensile strength, good stiffness, low cost, and abundant availability, especially in South Asian countries. Jute has been extensively used in composites and continues to be a benchmark for evaluating new natural fibers.

In this study, attention has turned toward less explored plant-based fibers, such as those derived from agricultural waste. Okra (Abelmoschus esculentus) is one such novel source. India is the world's largest producer of okra, primarily cultivated for its edible fruit. However, post-harvest, the stems are usually discarded as waste, despite being rich in cellulose fibers. Okra fiber remains underutilized but shows significant promise due to its high cellulose content, low density, good tensile properties, and potential for energy absorption, key characteristics for impact-resistant applications like automotive bumper systems (Satyanarayana et al., 2009).

Automotive bumper beams are designed to absorb energy during low-speed collisions, thereby reducing damage and enhancing occupant safety. Conventional materials such as steel, aluminum, and synthetic composites (e.g., glass fiber-reinforced polymers) are effective but come with drawbacks including high cost, limited recyclability, and environmental concerns (Alves et al., 2010). The bumper accounts for about 10-15% of vehicle sprung weight. Thus, it becomes a potential unit for weight reduction. The replacement of steel with optimally designed composite Automotive Bumper can provide 93% weight reduction. In this era of electrically driven cars composite beam will be more effective. The development of a composite material using jute and okra fibers could provide a lightweight, cost-effective, and sustainable alternative for bumper beam applications.

This research aims to develop and characterize a novel polypropylene composite reinforced with jute and okra fibers for use in automotive bumper beam systems. The study includes fiber extraction and treatment, composite fabrication through compression molding, and comprehensive testing to evaluate tensile, flexural, impact, and moisture absorption properties. The mechanical performance of the okra-based composite is compared with that of jute-based and conventional materials to assess its viability as a reinforcement in automotive structural components.

## 2.1 NEED OF INVESTIGATION

- To investigate the potential of okra fiber, an underutilized natural resource, as a novel reinforcement material in polymer composites for automotive applications.
- To enable the value-added utilization of okra plant stems - an abundant source of agricultural waste - by converting them into sustainable engineering materials.
- To evaluate the suitability of okra fiber for composite applications in comparison with established natural fibers such as jute, banana, flax, and sisal.
- To develop a lightweight and eco-friendly okra fiber-reinforced composite as a viable alternative to conventional materials currently used in automotive components.
- To assess and compare the mechanical performance of okra fiber-reinforced bumper beam composites with traditional bumper beam materials, focusing on parameters such as strength, impact resistance, and weight reduction.

## 2.2 PROBLEM STATEMENT

- Conventional materials used in automotive bumper beams - such as metals and synthetic fiber-reinforced composites - offer high strength but are typically heavy, non-renewable, and environmentally unsustainable.
- These materials contribute to increased fuel consumption and carbon emissions, while also presenting significant challenges in terms of recycling and end-of-life disposal.
- Natural fiber-reinforced composites like jute offer environmental benefits and weight reduction for automotive applications, but the potential of okra fiber with similar potential properties remains underexplored; which can a viable complement to jute in composite material.

- Okra fiber, which is rich in cellulose, is an agricultural by-product that remains largely unutilized in India, with the stems commonly discarded after harvesting the fruit.
- Despite its promising properties, okra fiber has received little attention in composite material applications, particularly for structural components in the automotive sector.
- There is limited research available on the mechanical performance and moisture sensitivity of okra fiber-reinforced composites.
- Therefore, there is a clear need to develop and evaluate natural fiber-based composite materials incorporating okra and jute fibers for use in automotive bumper beam applications.
- This study seeks to address this research gap by investigating the feasibility of okra fiber - independently compare with jute - as a potential reinforcement alternative to conventional synthetic composite materials.

## 2.3 SCOPE OF THE STUDY

This study is confined to the development and characterization of polymer matrix composites reinforced with natural fibers, specifically jute and okra, using a compression molding process. The research primarily focuses on evaluating key mechanical and physical properties pertinent to automotive bumper beam applications. The scope of the investigation includes:

- Extraction of okra fibers from the locally available okra plant treated as agro-waste.
- Alkali treatment (NaOH) of okra and jute fibre to enhance fiber-matrix adhesion.
- Fabrication of composite specimens using compression molding with varying processing parameters.
- Mechanical characterization through tensile, flexural, and impact testing, conducted in accordance with ASTM standards.
- Moisture absorption testing to evaluate the environmental stability and durability of the composites.
- Comparative analysis of the mechanical and physical performance of okra and jute fiber-reinforced composites.

## 3. OBJECTIVES

The primary objective of this research is to develop and evaluate a new natural fiber-reinforced polypropylene composite using okra and jute fibers for potential application in automotive bumper beam systems. The specific objectives include:

- To extract okra fibers from locally cultivated okra plant stems, and chemically treat using alkali (NaOH) treatment, aimed at improving fiber-matrix interfacial bonding.
- To fabricate polymer matrix composites reinforced with jute and okra fibers using the compression molding technique, incorporating variations in fiber weight fraction, fiber length, and the use of a binder.
- To perform mechanical testing - including tensile, flexural, and impact tests - according to relevant ASTM standards, in order to evaluate the structural performance of the developed composites.
- To investigate the moisture absorption behavior of the composites and assess their environmental suitability for automotive applications.
- To compare the mechanical and physical performance of okra fiber-reinforced composites with those reinforced by jute and conventional bumper beam materials, focusing on parameters such as tensile, flexural and impact strength with moisture absorbency.
- To evaluate the potential of okra fiber as a reinforcement material for semi-structural components in the automotive sector.

## 4. LITERATURE REVIEW

The emphasis on being environmentally friendly and sustainable in engineering has raced up research on natural fibre reinforced polymer composites (NFRPCs). Compared to synthetic materials, NFRPCs have a lower density, biodegradable, cheaper, and have less of an effect on the environment (Mohanty et al., 2005). Also, there has been a lot of interest in using them in the automotive industry, especially for non-structural and semi-structural parts, to make cars lighter and more fuel-efficient.

### 4.1. Okra Fiber and Its Potential in Composites

The growing need for low-density, environmentally friendly, and sustainable materials for engineering applications has drawn a lot of attention to the use of natural fibres to reinforce polymer composites in recent years. Because of their low density, biodegradability, renewability, and advantageous mechanical properties, fibres like jute, flax, hemp, and sisal have been the focus of much research and development. Despite their potential for composite applications, low-value and underutilised agricultural residues, like okra fibre (Abelmoschus esculentus), have not been sufficiently investigated.

The okra fibre bast fibre extracted from the stem of okra plant. The stem of the okra plant thrown away after harvesting of okra fruit as an agricultural waste. The high content of cellulose and hemicellulose in okra fibre, it has the potential to be used for fibre reinforced composites manufacturing. The cellulose content in the okra fibre is similar to that of commonly used bast fibres and a tensile strength ranging from 200 to 500 MPa, therefore it is utilised for the potential for structural and semi-structural applications, according to Kolte et al. (2020).

The alkali treatment specifically NaOH recommended to enhance the surface morphology of natural fibers by removing amorphous components such as lignin, hemicellulose, and surface waxes. As a result, the fibre and matrix have a stronger interfacial bond, improving the mechanical properties of composite materials. It was discovered that okra fibres treated with alkali were more compatible with thermoplastic and thermosetting matrices (Senthilkumar et al. 2020). There is currently a dearth of comprehensive, standardised, and benchmarked data on the mechanical characteristics of okra fiber-reinforced composites, particularly for tensile, flexural and impact loading condition.

The critical analysis of okra fiber properties proved that like other bast fibers; okra fiber possesses the potential to use for various applications like fiber-reinforced composites, home textiles, knitted and non-woven textile goods, rope making, etc. Also, from this critical experimental investigation, it is found that there is scope to analyze the potential of the Indian okra fiber for various textile applications viz. okra fiber reinforced composite material, bio composite material, automotive panels, seat covers, bumper beams for light weight E-vehicles; agro-product storage bags or sacks; acoustic material; sanitary pads in medical textile, house-hold material like table cover, footboard, sofa cover, etc. experimentally (Kolte, P. P., & Shivankar, V. S. (2024) .

Moisture absorption, a known issue for natural fibre composites, has a significant impact on dimensional stability and long-term durability. Sharma and Thomas (2019) have observed that the hydrophilic nature of okra fibres makes them vulnerable to moisture absorption. This drawback can be mitigated, though, by employing matrix systems with low moisture permeability and appropriately altering their surfaces.

Notwithstanding promising initial findings, comprehensive research on the application of okra fibre composites in automotive components is conspicuously lacking, particularly in bumper beam systems where material performance in terms of energy absorption, weight reduction, and impact resistance is critical. Most existing studies focus on general mechanical characterization and do not consider the application-specific requirements of the automotive industry.

### 4.2. Jute Fibre for Composite Material:

Natural fiber-reinforced polymer composites, or NFRPCs, are becoming more and more popular in the automotive sector as environmentally friendly substitutes for traditional materials. Growing environmental concerns, legal requirements, and the need for lightweight materials to improve fuel economy and lower greenhouse gas emissions are the main causes of this change. Jute has become a particularly promising reinforcement in composite materials among the many natural fibres that have been studied because of its favourable mechanical properties, affordability, biodegradability, and widespread availability in places like South Asia. (Kolte, P. P., & Shivankar, V. S. (2023)

The mechanical performance of Jute fiber-reinforced composites (JFRCs) has been thoroughly studied in the literature. For example, when Alam et al. (2015) assessed jute/polypropylene composites, they discovered that surface modification and fibre loading had a

significant impact on the tensile and flexural characteristics of composites. By eliminating surface impurities and raising surface roughness, chemical treatments like sodium hydroxide (NaOH) alkali treatment have been shown to improve fiber–matrix interfacial bonding, stress transfer, and overall mechanical behaviour (Kabir et al., 2012).

The suitability of jute composites for semi-structural applications in the automotive sector has also been the subject of many researches. Dhakal et al. (2007) examined the impact characteristics of polyester composites reinforced with jute and found that these materials offer sufficient energy absorption for low-impact components.

However, a major disadvantage of jute fibre composites is their sensitivity to moisture. Moisture absorption can ultimately result in dimensional instability, a breakdown in fiber-matrix adhesion, and a decrease in mechanical performance because jute is hydrophilic (Bledzki et al., 2002). To reduce these effects and boost durability in a range of environmental conditions, fibre surface treatments, hydrophobic matrix systems, and composite hybridisation have all been proposed.

Jute-based composites have already been adopted for industrial use by major automotive manufacturer. Jute and other natural fibre composites have been successfully integrated into non-structural vehicle components by Ford, Toyota, and BMW as part of broader efforts to reduce vehicle weight and environmental impact (Bourmaud et al., 2019).

However, further study is required to enhance the overall mechanical performance, moisture resistance, and processing techniques of jute composites, especially for use in semi-structural or structural automotive applications. The creation of next-generation jute fibre composites with exceptional performance characteristics suited for demanding engineering applications is made possible by recent advancements in nano-reinforcement and biopolymer matrix systems.

### 4.3. Surface Treatment and Fiber-Polymer Bonding

The hydrophilic nature, which results in poor interfacial adhesion with matrices of hydrophobic polymers, is the main disadvantage of natural fibres like okra and jute. This weak fiber-matrix bonding commonly leads to reduced mechanical performance in composite materials. Alkali treatment with sodium hydroxide (NaOH) is one of the most popular chemical treatments used to enhance fiber-matrix compatibility.

Hemicellulose, lignin, pectin, waxes, and surface contaminants are among the non-cellulosic materials that are partially removed during the NaOH treatment, also known as mercerisation. This procedure improves mechanical interlocking and interfacial adhesion with the polymer matrix by roughening the fibre surface and exposing more hydroxyl groups (Li et al., 2007). For jute fibres, the efficacy of this treatment has been extensively documented; after alkali treatment, both thermoplastic and thermoset-based composites showed increased tensile strength and flexural modulus (Kabir et al., 2012; Alam et al., 2015).

Recent studies have shown the potential of okra fibres, despite the fact that they have not been studied as thoroughly as jute. According to Senthilkumar et al. (2020), okra fibres treated with 5% NaOH for two hours showed improved bonding with epoxy matrices, which improved the tensile and impact property of composites. Similar to this, Sharma and Chauhan (2019) found that alkali-treated okra fibres had improved wettability and dispersion within polyester matrices, leading to more consistent stress transfer and enhanced mechanical response.

The elimination of amorphous materials and partial delignification, which lessens fibre swelling and enhances dimensional stability, are responsible for the improvement in interfacial bonding. Nonetheless, careful optimisation of the NaOH concentration in treatment and duration is required. Overexposure can harm the crystalline cellulose regions and cause over-delignification, which weakens the fibre structure and lowers the mechanical integrity of the fibres (Bledzki et al., 2002; John & Thomas, 2008).

In both jute and okra fiber-reinforced composites, surface treatment with NaOH is essential for enhancing the fiber-matrix interface. The chemical compatibility and bonding efficiency with polymer matrices are greatly improved by roughening the surface and eliminating non-cellulosic components. Although promising, okra fibre needs more optimisation in terms of treatment parameters and long-term durability evaluation, whereas jute fibre has a long history in composite applications. In many engineering fields, the incorporation of treated jute and okra fibres into composite systems offers a practical, sustainable substitute for synthetic reinforcements by striking a balance between environmental benefits and mechanical performance.

### 4.4 Natural Fiber Composites in Automotive Applications

Natural fiber-reinforced polymer composites (NFRPCs) have garnered a lot of attention as potential substitutes for traditional synthetic fibre composites due to growing need of the

automotive industry for lightweight, environmentally friendly, and sustainable materials. The low density, renewability, biodegradability, and low environmental impact of natural fibres like jute, flax, hemp, kenaf, sisal, and coir make them ideal for incorporation into a variety of automotive components (Mohanty et al., 2005; Pickering et al., 2016).

NFRPCs have been used more often in the automotive industry for semi-structural and interior applications with the goals of lowering vehicle weight, improving fuel economy, and meeting ever-tougher environmental standards. Nowadays, door panels, dashboard trims, seat backs, package trays, and insulation components are all made of these composites, which successfully replace more conventional materials like glass fiber-reinforced plastics (Holbery & Houston, 2006). Natural fibres typically have a density of 1.2 to 1.5 g/cm$^3$, which is much lower than that of glass fibres (~2.5 g/cm$^3$). This allows for significant weight reductions in components (Suddell & Evans, 2005).

A number of variables, such as fibre type, matrix selection, fibre orientation, and the strength of the fiber-matrix interfacial bonding, affect the mechanical performance of NFRPCs. While natural fibres typically have lower stiffness and tensile strength than their synthetic counterparts, like glass fibres, a variety of surface modification techniques, such as acetylation, silane coupling, and alkali (NaOH) treatment, have been used to improve mechanical integrity and interfacial adhesion (Li et al., 2007; Kabir et al., 2012). According to experimental studies, if processing parameters are optimised, composites reinforced with treated flax, jute, or hemp fibres can meet mechanical performance benchmarks for specific automotive components (Wambua et al., 2003).

Natural fibre composites have been successfully integrated into commercial vehicle designs by major automakers such as Ford, Toyota, Mercedes-Benz, and BMW. In order to reduce weight and improve its thermal and acoustic insulation qualities, BMW, for example, uses kenaf fiber-reinforced composites in its door panels and rear shelves (Shah, 2014). These real-world applications are in line with more general developments in the automotive sector, especially with regard to circular economy and sustainable material innovation tactics.

NFRPCs still have technical issues despite their benefits, especially with regard to moisture absorption, dimensional stability, flammability, and inconsistent fibre characteristics. The hydrophilic properties of natural fibres aid in moisture absorption, which can cause fibre swelling, weakened interfacial bonds, and long-term mechanical deterioration, particularly in damp or high-

humidity environments (Bledzki & Gassan, 1999). To improve the durability and dependability of these materials in increasingly demanding automotive environments, recent research efforts have concentrated on creating hybrid composite systems, using hydrophobic matrices, and applying barrier coatings (Puglia et al., 2018; Faruk et al., 2012).

In conclusion, the drawbacks of natural fibre composites are gradually being overcome by developments in fibre surface treatment, matrix formulation, and composite processing. Because of this, NFRPCs are becoming more and more recognised as sustainable and practical substitutes for synthetic composites in a range of automotive applications. Their performance should be further enhanced by ongoing research and industrial development, allowing for wider use in semi-structural and non-structural components that satisfy the environmental, mechanical, and thermal requirements of contemporary automotive engineering.

### 4.5 Compression Molding and Mechanical Testing

The compression moulding technique provides high dimensional accuracy, uniform thickness, and consistent quality composites; therefore, it is a commonly used manufacturing technique for the fabrication of fiber-reinforced composites. Both thermoplastic and thermoset matrices reinforced with synthetic or natural fibres work especially well with this technique. Natural fiber-reinforced composites made by compression moulding have been shown in numerous studies to have good mechanical performance, especially in terms of tensile and flexural strength (Joshi et al., 2004).

Testing methods are frequently carried out in compliance with ASTM (American Society for Testing and Materials) standards to assess the structural and environmental behaviour of these composites. By making it easier to repeat and compare evaluations of characteristics like mechanical strength, impact resistance, and moisture absorption, these standardised procedures guarantee the accuracy and consistency of experimental data from various investigations.

### 4.6 Effect of Polypropylene (PP) Matrix with Jute and Okra Fibers

The polypropylene (PP) is one of the most widely used thermoplastic matrices due to its advantageous properties, including low density, good chemical resistance, ease of processing, and relatively low cost, (Mohanty et al., 2005). There are few studies on okra fibres alone in PP matrix,

but preliminary research suggests that when properly treated and distributed, okra fibre can improve mechanical qualities like stiffness and strength (Mylsamy & Rajendran, 2011).

A lignocellulosic material called jute fibre has been thoroughly researched for use as reinforcement in PP composites. Numerous studies have demonstrated that appropriate fibre loading and treatment greatly enhance the mechanical performance of PP-jute composites. Roy et al. (2012), for example, showed that improved interfacial bonding with the PP matrix in alkali-treated jute fibres led to a significant improvement in tensile and flexural properties. The PP is hydrophobic and jute fibres are naturally hydrophilic in nature therefore, poor interfacial adhesion frequently results, leads to generate need of surface modification or compatibilizers like maleic anhydride grafted PP (MAgPP) (Joseph et al., 2002).

Ramesh et al. (2015) investigated natural fibre composites using PP and found that the right ratio of fibre types resulted in improved mechanical performance. Despite the lack of specific data on okra fibre PP composites, extrapolations from comparable systems point to possible gains in dimensional stability, modulus, and impact resistance.

In conclusion, although jute and okra fibres perform well individually in PP matrices, they may offer improved and balanced qualities for lightweight applications like consumer goods or interior car parts. However, more experimental data and optimization studies are necessary to fully exploit the potential of these underutilized fibers in PP composites.

### 4.7 Compatibilizer MAgPP Used for Improving Mechanical Properties in Polypropylene fibre reinforced composite

The incompatibility of the hydrophilic natural fibres and the hydrophobic PP matrix is an important challenge in the development of high-performance natural fiber/PP composites. This incompatibility leads to poor interfacial adhesion and, as a result, suboptimal mechanical properties (Mohanty et al., 2005).

Compatibilizers, especially maleic anhydride grafted polypropylene (MAgPP), have been widely used to enhance fiber–matrix adhesion in order to get around this restriction. MAgPP functions as a coupling agent, creating a chemical bridge across the interface as the maleic anhydride groups react with the hydroxyl groups on the surface of natural fibres while the PP backbone stays compatible with the polymer matrix (Joseph et al., 2002).

The beneficial effect of MAgPP on the mechanical performance of PP-based composites has been validated by numerous studies. Herrera-Franco and Valadez-González (2005), for instance, found that adding MAgPP to henequen fiber/PP composites increased the interfacial shear strength, which in turn improved the tensile and flexural strengths. In a similar vein, Joseph et al. (2003) found that adding 5 weight percent MAgPP to sisal/PP composites enhanced their tensile strength by 30 to 50%. This was ascribed to better stress transfer between the fibre and the matrix.

In their 1999 study of jute fiber-reinforced PP composites, Karmakar and Joseph discovered that adding MAgPP significantly increased the modulus, tensile strength, and impact strength of composites, particularly when the fibres had previously been alkali-treated. Alkali treatment exposes cellulose fibrils, increasing their reactivity with maleic anhydride groups, which results in this synergistic effect. Additionally, Paul and Joseph (2001) showed that using MAgPP enhanced the wettability and dispersion of fibres in the PP matrix, improving toughness and dimensional stability.

A tried-and-true technique for improving the mechanical characteristics of PP-based natural fibre composites is the compatibilizer MAgPP. It enhances tensile strength, flexural modulus, impact resistance, and dimensional stability by fostering a strong interfacial bond. To maximise its impact, the right dosage and fibre surface treatments are essential. In order to successfully integrate novel fibres like okra into PP matrices for advanced composite applications, it is still crucial to strategically use MAgPP.

## 5. CONTRIBUTION

### 1. Experimental Procedure Steps:

Raw Material Collection and Preparation (Fibre, Matrix, and Binder)

Chemical Treatment of Fibers

Fiber Characterization

Composite Fabrication

Composite Optimization and Mechanical Testing

Development for Bumper Beam

### 2. Extraction of Okra fibre and Collection of jute fibre

**Fig 1. Okra Fruit**

**Fig 2. Okra Plant**

Okra fiber is the natural cellulosic bast fiber extracted from the bark of the Abelmoschus esculentus plant stem. India is the largest producer of okra for the cultivation of "okra fruit." After harvesting the okra plant in the field, the okra fruit is collected as a vegetable, and the okra plant is thrown out as agricultural waste. In India, an estimated 4.5 million tons of green okra plants were discarded annually as agricultural waste. The okra plant has the potential to produce 150–160 kg of okra fibers per hectare and about 13.4 million kg of okra fibers annually. The okra plant is cultivated in two seasons: summer and winter. The summer variety (SV) and winter variety (WV) were extracted from okra plants cultivated in the summer and winter seasons, respectively. The jute fibre generally utilized for various textile applications collected from the market. The characteristics of the varieties of okra and jute fibers (morphological, thermal, and structural) are investigated by optical and electron microscopy (SEM), thermogravimetric analysis (TGA, DTG, DSC), X-ray diffraction analysis (XRD), and Fourier transform infrared spectrometry (FTIR).

## 2.1 Result and Discussion

The analysis of the morphological, thermal and structural properties of the okra fibre varieties shows significant behaviour. The comparative analysis of both variety okra and jute fiber properties with the other bast fibres proved their potential for various commercial applications like fiber-reinforced composites, home textiles, knitted and non-woven textiles, rope-making, etc. Also, engendered scope to analyse the potential of the SV and WV okra fiber for various textile applications, viz., okra fiber reinforced composite material, bio-composite material, automotive panels, seat covers, bumper beams for lightweight E-vehicles, agro-product storage bags or sacks, acoustic materials, sanitary pads in medical textile, household materials like a table cover, footboard, sofa cover, etc., experimentally.

Also, after the comparison of SV and WV okra fibre, SV okra fibre depict superior morphological, thermal and structural characteristics, therefore SV okra fibre decided to use for the further composite material development study. In the literature review, many studies proved the potential for the utilization of jute fibre for automotive application. Therefore, commercially available quality jute fibre used for the study. The morphological, thermal and structural properties of the procured jute fibre analysed, which are found nearly similar to okra fibre.

**Table 1. Physical properties of some other natural fibres in comparison to okra fibres.**

| Fiber | Length (m) | Diameter (µm) | Fineness (tex) | Cross-sectional shape | References |
|---|---|---|---|---|---|
| Indian Okra | 0.5-2.0 | 60-100 | 6.0-13.0 | Polygonal | This study |
| Foreign Okra | 0.5-4.0 | 40-180 | 6.0-14.66 | Polygonal | (9) |
| Ramie | 1.5 | 60-900 | 0.51-0.71 | Hexagonal | |
| Abaca | >2.0 | 10-280 | 4.2-44.44 | Round/Oval | |
| Banana | 0.8-2.8 | 11-34 | 6.0-7.56 | Cylindrical | |
| Sisal | 1.0 | 100-460 | 1.0-45.1 | Cylindrical | |
| Coir | | 100-450 | | Polygonal | |
| Flax | 0.2-1.4 | 40-620 | 0.19-1.98 | Polygonal | (10) |
| Jute | 1.5-3.6 | 30-140 | 1.44-3.0 | Round/Oval | |
| Kenaf | | | 5.56 | Cylindrical | |
| Hemp | 1.0-3.0 | | 0.33-2.22 | Polygonal/Oval | |

**Table 2. Chemical Composition some other natural fibres in comparison to okra fibre.**

| Types of fibre | Cellulose (Wt.%) | Hemi-cellulose (Wt.%) | Lignin (Wt.%) | Pectin (Wt.%) | Moisture Content (Wt.%) | Wax (Wt.%) | Ref. |
|---|---|---|---|---|---|---|---|
| Banana | 28.3-35.8 | 12.94-17.2 | 14.4-15.8 | 4.7 | 8.5-9.5 | | (15) |
| Flax | 64.1–71.9 | 16.7–20.6 | 2.0–2.2 | 1.8–2.3 | 8–12 | 1.7 | (47) |
| Hemp | 70.2–74.4 | 17.9–22.4 | 3.7–5.7 | 0.9 | 6.2–12 | 0.8 | |
| Jute | 61–71.5 | 12.0–20.4 | 11.8–13 | 0.2 | 12.5–13.7 | 0.5 | |
| Kenaf | 31–57 | 21.5 | 8–19 | 3–5 | | | |
| Ramie | 68.6–76.2 | 13.1–16.7 | 0.6–0.7 | 1.9 | 7.5–17 | 0.3 | |
| Okra | 60–70 | 15–20 | 5–10 | 3.7 | 8.2-8.8 | 3.9 | (5) |

**Table 3. Properties of SV and WV okra fiber**

| Fiber properties | Summer variety of okra fiber (SV) | Winter variety of okra fiber (WV) |
|---|---|---|
| Fiber Length (m) | 0.5-2.0 | 0.1-0.4 |
| Fiber density (gm/cm$^3$) | 1.20-1.42 | 1.15-1.52 |
| Fiber Diameter (µm) | 60-100 | 33-65 |
| Fineness (tex) | 8.0-13.0 | 3.0 – 9.0 |
| Tenacity (gram/tex) | 32-51 | 22-39 |
| Crystallinity (%) | 25.8 | 25.0 |
| Slenderness ratio | 130-215 | 174-236 |
| Ash (%) | 3-5 | 2-3 |
| Extension (%) | 1.6-3.0 | 1.8-3.1 |
| Colour | Light cream | Light cream |

## 3. Surface modification of okra and Jute fibre by NaOH treatment

The surface modification of natural bast fibres by NaOH treatment is performed to increase surface roughness, removal of outer layer (lignin, hemicellulose, wax) and other impurities which enhance the fibre-matrix adhesion for composite materials. The NaOH treatment significantly influencing the weight loss, absorbency and tensile properties of the natural bast fibres.

The NaOH treatment on okra and jute fibre shows the significant weight loss due to removal of lignin, hemicellulose, waxes and impurities, which improve interfacial bonding in composites. Also, NaOH treatment leads to increase water absorbency initially but later on it reduces due to pore collapse and fibre degradation. The tensile strength and elongation at break of both okra and fibres also reduced due to fibre degradation, removal of binding agent i.e. lignin and surface erosion.

**Table 4. Weight loss of okra fibre after NaOH treatment**

| Sr. No. | Sample | Weight of untreated sample (gm) | Weight after NaOH treatment (gm) | | Weight loss [%] | |
|---|---|---|---|---|---|---|
| | | | Okra | Jute | Okra | Jute |
| 1 | 2% NaOH at 100 degree, 2hrs | 50 | 46.23 | 45.44 | 7.54 | 9.12 |
| 2 | 5% NaOH at 100 degree, 2hrs | 50 | 43.86 | 43.52 | 12.28 | 12.96 |
| 3 | 5% NaOH treated at room temp., 24hrs | 50 | 45.93 | 45.70 | 8.14 | 8.14 |

**Table 5. Water absorbency of okra fibre after NaOH treatment**

| Sr. No. | Sample No. | Water absorbency% | |
|---|---|---|---|
| | | Okra | Jute |
| 1 | Untreated okra fiber | 62.11 | 56.41 |
| 2 | 2% NaOH at 100 degree, 2hrs | 65.19 | 59.12 |
| 3 | 5% NaOH at 100 degree, 2hrs | 65.46 | 59.89 |
| 4 | 5% NaOH treated at room temp., 24hrs | 63.93 | 57.95 |

**Table 6. Tensile behaviour of okra fibre after NaOH treatment**

| Sr. No. | Sample No. | Gauge length [mm] | Strain rate [mm/min] | Tenacity [gf/tex] | | Elongation at break [mm] | |
|---|---|---|---|---|---|---|---|
| | | | | Okra | Jute | Okra | Jute |
| 1 | Untreated | 50 | 30 | 11.58 | 10.15 | 1.4 | 1.8 |
| 2 | 2% NaOH at 100 degree, 2hrs | 50 | 30 | 9.81 | 8.98 | 1.1 | 1.3 |
| 3 | 5% NaOH at 100 degree, 2hrs | 50 | 30 | 9.6 | 8.8 | 0.89 | 1.4 |
| 4 | 5% NaOH treated at room temp., 24hrs | 50 | 30 | 8.83 | 8.58 | 1.1 | 1.35 |

## 4. Okra and Jute fibre reinforced composites preparation

A compression moulding machine is used to fabricate the okra and jute fibre composites. A polypropylene (PP) matrix utilised with a binder Maleic Anhydride grafted polypropylene (MAgPP) to enhance the fibre-matrix adhesion for composite materials. The properties of the PP matrix abd MAgPP binder mentioned in the following table.

**Table 7. Properties of PP Resin**

| **Resin Properties** | **Unit** | **Data** |
|---|---|---|
| Melt Flow Index (230$^{o}$C & 2.16 Kg) | gm/10 min | 12 |
| Density @ 23$^{o}$C | gm/cm$^{3}$ | 0.9 |
| Tensile Strength @ Yield (50 mm/min) | MPa | 27 |
| Elongation @ Yield (50 mm/min) | % | 8 |
| Flexural Modulus (1.3 mm/min) | MPA | 1100 |
| Notched Izod Impact Strength @ 23$^{o}$C | J/m | 80 |

**Table 8. Properties of MAgPP Binder**

| **Binder Properties** | **Unit** | **Data** |
|---|---|---|
| Melt Flow Index (190$^{o}$C & 2.16 Kg) | gm/10 min | 110 |
| Density @ 23$^{o}$C | gm/cm3 | 0.908 |
| Tensile Strength @ Yield (50 mm/min) | MPa | 29 |
| Elongation @ Yield (50 mm/min) | % | 6 |
| Flexural Modulus (1.3 mm/min) | MPA | 1850 |
| Notched Izod Impact Strength @ 23$^{o}$C | J/m | 74 |

**Fig 3. Compression Molding Machine**

**Fig 4. Close mold size**

The performance of the okra and jute fibre reinforced composite material analysed with following variables:

- Fibre Length: 10mm, 20mm, 30mm
- Fibre proportion by weight: 10%, 20%, 30%
- NaOH treated Fibres: 30mm length and 30% fibre proportion
- MAgPP binder proportion by weight: 10, 20, 30%)

Prepared okra and jute fibre reinforced composites undergo mechanical testing (i.e tensile, impact and flexural), and moisture absorption analysis to assess the impact of fibre reinforment and treatment. The tests were performed according to ASTM standard mentioned below:

Tensile Properties: (ASTM D3039)

- Universal Testing Machine
- Tensile strength (MPa)
- Sample size is L= 165mm; B = 13mm; H = 10mm.

Flexural Properties: (ASTM D7264)

- Universal Testing Machine
- Flexural Strength (MPa) (Central point loading)
- Sample size is L= 127mm B= 12.7mm H= 10mm

Impact Properties: (ASTM D256)

- Charpy Impact strength (for ductile material) (KJ/m2)
- Sample size is L= 65mm B= 13mm H= 10mm

Moisture absorbency: (ASTM D5229)

- Sample size is L= 10mm B= 10mm H= 10mm

**4.1 Result and Discussion:**

***4.1.1 Tensile Test of composites:***

*4.1.1.1 Effect of fibre length on Tensile strength*

- It is observed that, tensile strength increases with the fibre length in okra and jute FRC.
- 30 mm length okra and jute FRC shows better tensile strength in all compositions.
- Tensile strength increases with the proportion of fibre in Okra and jute fibre reinforced composite.

*4.1.1.2 Effect of alkali treated fibre on Tensile strength*

- The alkali treated okra and jute fibre in the FRC shows slightly increase the tensile strength of jute and okra fibre composite.
- For 10% fibre proportion in composite shows significant rise in strength for jute fibre composite.

*4.1.1.3 Effect of binder on Tensile strength*

- MAgPP binder increases the tensile strength of both okra and jute FRC.
- Results are more significant for okra fibre reinforced composite.
- It is observed that the FRC stiffness increases with increase in the binder proportion.

***4.1.2 Flexural Test of composites:***

*4.1.2.1 Effect of fibre length on Flexural strength*

- Flexural strength of the jute and okra FRC increases with increase in fibre length and proportion in both okra and jute FRC.
- Improvement in flexural strength is less significant for 10mm fibre length FRC.

*4.1.2.2 Effect of alkali treated fibre on Flexural strength*

- The alkali treated okra and jute fibre in the FRC not shows significant effect on flexural strength of FRC.
- But the significance difference shows as increasing fibre proportion in FRC.

*4.1.2.3 Effect of binder on Flexural strength*

- Use of MAgPP binder in okra and jute fibre in the FRC shows significant effect on flexural strength of okra and jute FRC.
- The significant difference shows with increasing MAgPP proportion and fibre proportion in FRC.

***4.1.3 Impact Test of composites:***

*4.1.3.1 Effect of fibre length on Impact strength*

- Impact strength of the FRC increases with the length as well as proportion of okra and jute fibre in the FRC.
- Improvement is more significant in okra FRC.

*4.1.3.2 Effect of alkali treated fibre on Impact strength*

- The alkali treated okra and jute fibre in the FRC not shows significant effect on impact strength of FRC.
- The NaOH treated jute FRC shows slight decrease in impact strength.

*4.1.3.3 Effect of binder on Impact strength*

- The impact strength of FRC is slightly increases with the use of MagPP.
- The results were more significant for Jute FRC.

### 4.1.4 Moisture absorbency test of composites

*4.1.4.1 Effect of fibre length on Moisture absorbency*

- The moisture absorbency of the FRC reduces with the increase in fibre length for both jute and okra fibre composite material.
- The proportion of the okra and jute fibre in the composite material slightly increase moisture absorbency of the FRC.
- As compare to okra fibre composite, jute fibre composite shows more moisture absorbency.

*4.1.4.2 Effect of alkali treated fibre on Moisture absorbency*

- The moisture absorbency of jute and okra fibre composite material increases by using alkali treated fibre.
- Increase in the absorbency is more for jute fibre composite than the okra fibre composite material.
- The proportion of the okra and jute fibre in the composite material slightly increase moisture absorbency of the FRC.

*4.1.4.3 Effect of binder on Moisture absorbency*

- The moisture absorbency of the FRC increases with the utilization of binder for both jute and okra fibre composite material.
- The proportion of binder in the composite material slightly increase moisture absorbency of the FRC.
- As compare to okra fibre composite, jute fibre composite shows more moisture absorbency with binder utilization.

### 4.2 Summary:

- Increase in the fibre length; tensile, flexural, and impact strength of both okra and jute FRC increases.
- 30 mm length okra and jute FRC shows better tensile, flexural, and impact strength in all compositions.
- Increase in the fibre proportion; tensile, flexural, and impact strength of both okra and jute FRC increases.
- 30% okra and jute fibre proportion by weight in FRC shows better tensile, flexural, and impact strength in all compositions.
- Alkali treated okra and jute fibre composite not shows significant increase in the tensile, flexural, and impact strength.
- Utilization of binder in the okra and jute fibre composite shows slight increase in the tensile, flexural, and impact strength.
- Moisture absorbency of okra and jute fibre composite reduces with increase in fibre length; but increases with increase in fibre proportion.
- Alkali treatment to fibres and utilization of binder in composite increases the moisture absorbency of both okra and jute fibre composite.

## 5. Okra woven and non-woven fabric reinforced composites

The stem of the Abelmoschus esculentus plant yields okra fibre, which has garnered interest as a sustainable reinforcing material due to its low density, intermediate mechanical properties, and biodegradability. Both woven and non-woven fabrics can be made from okra fibre by processing it into textile structures; each has advantages of its own. Woven okra fabrics, which have excellent tensile and dimensional stability in both the warp and weft directions, are made by interlacing yarns in a structured pattern, typically plain weaves. Because of their higher mechanical strength, these textiles are ideal for applications where directional loading and reinforcement are essential.

In contrast, non-woven okra textiles are composed of randomly aligned fibres that are connected by mechanical entanglement. Non-wovens are suitable for applications needing flexibility or even load distribution since they are less expensive, simpler to manufacture, and have

isotropic properties. Non-wovens significantly increase the interfacial area and fibre alignment in polymer composites when compared to chopped or short fibres.

Both woven and non-woven fabrics improve fibre alignment and fiber-matrix contact area compared to randomly dispersed short fibres, which improves mechanical performance and stress transfer of composites. Fabric-based reinforcements also reduce fibre pull-out and delamination under tensile and flexural pressures. Okra-based composites comprising woven and non-woven textiles have shown potential for usage in packaging, automobile panels, and lightweight, biodegradable furniture components.

The specification of the okra woven and non-woven fabric is as follows:

1] Okra Woven Fabric Details:

Weft count: 15 Ne

Warp count: 15 Ne

Ends Per Inch: 30

Picks Per Inch: 30

Twist Per Inch : 5

2] Okra-Polypropylene non-woven fabric details:

GSM: 1200

Okra: 65%

Polypropylene: 35%

Top Punching: 7 mm penetration

Botton Punching: 13 mm penetration

Needle Density: 5000 needles/sq. m.

**5.1 Result and Discussion**

PP composites accompanied with natural fibres, particularly jute and okra fibres, provide a practical and sustainable alternative. For the random okra fiber-reinforced PP composite, the tensile strength ranged from 25 to 42 MPa, the flexural strength ranged from 50 to 73 MPa, and the impact strength ranged from 38 to 60 J/m. These values are equivalent to those of commercially available natural fibre composites and are suitable for semi-structural applications such as bumper beams in LMVs. However, high moisture absorption (8-9%) remains challenging because it can affect dimensional stability and long-term durability.

In this investigation the polypropylene composites produced using okra-woven fabric reinforcement was significantly superior in performance. The tensile strength (52 MPa), flexural strength (74 MPa), and impact strength (62 J/m) are substantially greater than those of randomly distributed natural fibre composites and nearly equal the performance of synthetic Glass Fibre polypropylene composites. The improvement is attributed to improved fibre orientation, weaving architecture, and stress distribution in the woven form. Although slightly inferior to the woven variant, okra non-woven fabric-reinforced polypropylene composites also showed promising results (impact strength: 58 J/m, tensile strength: 44 MPa).

**Table 9. Mechanical Properties of FRC for Bumper Beams**

| **Materials** | **Tensile Strength (MPa)** | **Flexural Strength (MPa)** | **Impact Strength (J/m)** | **Moisture Absorbency (%)** | **Ref.** |
|---|---|---|---|---|---|
| Conventional steel | 200–500 | 250–500 | 250–500 | Nil | 73-75 |
| Advanced high-strength steel | 500–1500 | 500–1500 | 500–1500 | Nil | |
| Aluminum alloys | 200–500 | 200–500 | 200–500 | Nil | |
| Glass fiber-reinforced polypropylene | 50–80 | 90–150 | 70–150 | 0.5-1 | |
| Carbon fiber-reinforced polypropylene | 200–400 | 200–400 | 100-115 | 0.5-1 | |
| Glass-mat-reinforced thermoplastics | 100–300 | 100–300 | 40-120 | 0.5-1 | |
| Okra fibre reinforced PP composite | 25-42 | 50-73 | 38-60 | 8-9 | This study |
| Jute fibre reinforced PP composite | 20-40 | 32-50 | 35-54 | 7.5-8 | |
| Okra woven fabric reinforced PP composite | 52 | 74 | 62 | 6.1 | |
| Okra Non-woven fabric reinforced PP composite | 44 | 56 | 58 | 7.3 | |

When the proper surface modification techniques (such as alkaline treatment) are applied to enhance their hydrophobicity and interfacial bonding, woven and non-woven okra fabric composites can be utilised in automobile applications, despite the fact that they absorb more moisture (6-7.5%).

In conclusion, the study demonstrates the potential of okra fibre, an underutilised agricultural waste, as reinforcement in automotive composites. With further refinement, particularly in the areas of moisture resistance and processing techniques, these materials can be more economical, lightweight, and ecologically friendly than synthetic fibre composites for LMV bumper beams.

### 5.2 Summary

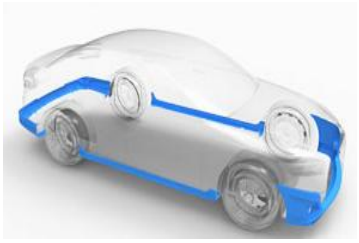
- Okra woven fabric-reinforced PP composites have competitive mechanical strength (Tensile: 52 MPa, Flexural: 74 MPa, Impact: 62 J/m), making them suitable for lightweight bumper beams in LMVs.
- Composites composed of natural fibres, such as jute and okra, have a greater moisture absorption rate (6-9%) but a moderate mechanical performance; surface treatment could be required for automotive application.
- The okra-woven and non-woven fabric-reinforced PP composites have mechanical properties similar to those of synthetic FRPs (such GFPP) therefore; suitable for lightweight bumper beams in LMVs.
- While moisture absorption is a drawback, it can be mitigated by surface treatments like NaOH.
- These materials offer a cost-effective and sustainable alternative for automotive applications, especially in regions that prioritise the utilisation of agro-waste and biodegradable resources.

## 6. Application of okra fibre reinforced composite material for bumper beam for LMVs

The fabrication of an Okra Fibre-Polypropylene (PP) composite bumper beam entails combining natural fibre reinforcement with a thermoplastic matrix in order to develop a sustainable and lightweight structural component for automotive applications. The studied composition of fibre-matrix-binder, which provide the potential mechanical properties selected for the composite fabrication. In this study, a 30 mm long Okra fibre is used at 30% proportion by weight into a polypropylene matrix, along with 20% by weight of maleic anhydride-grafted polypropylene (MAgPP) as a compatibilizer, to develope interfacial adhesion between the hydrophilic fibres and the hydrophobic polymer matrix. The composite material was developed using a compression moulding process, which is ideal for producing uniform fibre dispersion and compact consolidation under controlled temperature and pressure conditions. This technology allows for

the development of a fiber-reinforced composite bumper beam with increased mechanical performance and environmental compatibility, providing a viable alternative to traditional synthetic-fibre-based components used in light motor vehicles.

The polypropylene (PP) or its composites are extensively used to create bumper beams for light motor vehicles (LMVs) such the Mahindra XUV700 and Hyundai Xcent. These materials were chosen because they are cost-effective, impact-resistant, lightweight, and easy to manufacture. To improve occupant safety and vehicle lifetime, PP bumper beams of these models are designed to effectively absorb crash energy while maintaining structural integrity.



Bumper beam

**Fig 5. LMVs Vehicle with Bumper Beam**

**Table 10. Comparison of Mechanical Properties Commercially Utilizing PP Bumper Beam with Okra Fibre-PP Composite Bumper Beam (For LMVs Vehicles)**

| **Material Type** | **Tensile Strength (MPa)** | **Flexural Strength (MPa)** | **Impact Strength (J/m)** | **Moisture Absorbency (%)** | **Ref.** |
|---|---|---|---|---|---|
| Glass Fiber-Reinforced PP (30–40%) | 50–80 | 90–150 | 70–150 | 0.1-0.3 | 69-72 |
| Impact-Modified PP (e.g., PP-EPDM) | 20–30 | 25–45 | 50–100 | 0.2-0.5 | |
| Natural Fiber–Reinforced PP (e.g., Jute/Kenaf) | 35–60 | 60–90 | 60–120 | 3-8 | |
| Neat Polypropylene (PP) | 25–35 | 30–50 | 30–50 | 0.01-0.05 | |
| Okra Fibre reinforced PP | **50.2** | **69.8** | **61.4** | **5.4** | This study |

The mechanical properties of Okra Fibre-PP composite bumper beams and commercially available polypropylene (PP) bumper beams are evaluated, and the use of natural fibres greatly increases performance. Because of the reinforcing action of the 30 mm long okra fibres and the use of MAgPP compatibilizer, which promotes fiber-matrix bonding, the Okra Fibre-PP composite has remarkable tensile strength, flexural strength, and impact resistance. This improvement

demonstrates higher energy absorption capacity and structural integrity under impact loading of the composites, making it an environmentally benign alternative to typical PP bumper beams utilised in light motor vehicles.

Okra fibre is an excellent reinforcement material due to its high *tensile strength* and stiffness. The fibres act as load-bearing elements in the polymer matrix. The addition of MAgPP compatibilizer improves stress transmission and tensile characteristics by strengthening the interfacial bonding between hydrophilic fibres and hydrophobic PP matrix.

Okra fibres, give good bending resistance because to their inherent rigidity. The 30 mm fibre length provides effective stress distribution and resistance to deformation under *flexural stresses*. Furthermore, matrix adhesion and fibre dispersion provide increased stiffness, which improves flexural performance.

Okra fibres boost the capacity to absorb energy by dissipating *impact energy* via fibre pull-out processes and microcracking. The composite structure can handle abrupt shocks better because of the improved matrix-fibre compatibility and toughening effect caused by fibre reinforcement.

Natural fibres, like as okra, are hydrophilic and absorb more moisture than synthetic polymers like . Because cellulose is contained in the fibre, MAgPP cannot totally prevent water uptake, even if it improves compatibility and reduces gaps. The increased moisture absorption compensates for the improved mechanical performance and sustainability of natural-fiber composites.

The comparison between the mechanical properties of commercially used PP bumper beam and okra and jute fibre PP composite beam shows that, the okra and jute fibre composite bumper beam can be utilized for LMVs vehicle bumper beam application. Mechanical properties such as tensile strength, flexural strength, Impact strength and moisture absorption% of the okra and jute fiber composites are not that much good like carbon or glass FRC but, has challenging properties compared to neat PP and other natural fibre composites like sisal, flax, jute etc. Also, it can be utilized for various interior and exterior automotive part applications as a fibre reinforced composite materials with medium range of mechanical properties.

## 6. Conclusion

The present study explored the development and performance assessment of okra and jute fibre reinforced composite material for automotive bumper beam application. In response to rising environmental apprehensions and demand of automotive industry for lightweight, eco-friendly composite materials, this research has proved natural bast fibre composite, specially using underutilized agricultural waste i.e. okra plant stem, can serve as a viable alternative to conventional synthetic composites.

**Potential of Okra Fibre:**

- The okra fibre extracted from agricultural waste (locally cultivated okra plant) has potential to use for fibre reinforced composite application like other bast fibres eg. Flax, sisal, etc.
- The comparison of the properties (Fiber Morphology, Chemical composition, TG, DTG and DSC curves, The X-ray diffractometer, The infrared Spectrograph) of okra fibre with other bast fibres proves its potential for various application.

**Okra and Jute Fibre Properties:**

- The properties of okra fibre and jute fibre are nearly similar.
- The thermal stability and structural properties of the okra and jute fibre are good and suitable for application of FRC.
- The surface modified okra and jute fibre shows better properties of the fibre except tensile strength which is slightly reduced.
- Moisture absorption% of the both fibre is high as like other natural fibre.

**Okra and Jute Fibre, and Okra Fabric Reinforced Composite Material Properties:**

This comprehensive research study including newly introduced underutilized okra fibre for composite application, fibre surface treatment, composite fabrication, testing of mechanical behaviour of composites, and moisture absorption analysis depicted that both okra and jute fibre enhancing the mechanical properties of popypropylene (PP) matrix significantly. The utilization of a compatibilizer Maleic Anhydride grafted polypropylene (MAgPP) improved tensile, flexural, and impact strength of the okra and jute fibre composites. Also, the developed composites depicted satisfactory moisture resistance, which is critical for vehicle durability and safety.

The composites with optimised fibre length, fibre volume fraction, and chemical treatment parameters showed promising potential among different formulations, meeting the mechanical performance criteria typically required for bumper beam components. In addition, the use of okra

fibre, a new and renewable reinforcement material, encourages the use of agricultural residues, which helps to reduce waste and boost the economy in rural areas.

- Mechanical properties such as tensile strength, flexural strength, Impact strength and moisture absorption% of the okra and jute fiber composites are not that much good like carbon or glass FRC but has challenging properties compared to other natural fibre composites like sisal, flax, banana etc.

**Commercially Utilizing PP Bumper Beam and Okra Fibre-PP Composite Bumper Beam (For LMVs Vehicles)**

This comprehensive study also analysed the mechanical properties of conventional polypropylene (PP) bumper beams with okra fiber-reinforced PP composite bumper beam for light motor vehicles (LMVs). The analysis depicted that the okra fiber–PP composite offers a possible alternative with potential mechanical properties and reduced environmental impact.

The reinforcement of okra fibre, an abundant agricultural waste, into the PP matrix providing light weight composite material can be utilized for LMVs vehicles bumper beam application.

Also, it can be utilized for various interior and exterior component parts automotive with the medium range of mechanical properties.

In conclusion, this study shows that okra fibre-PP composites have commercial potential for use in LMV bumper beams. With further research work and collaboration with industry, this bio-based solution might make a significant difference in the development of green automotive materials.

The cost of the investment in composite materials study is relatively high in the initial stage, but it will decrease with the improvement and maturity of the process. After that, the application of composite materials in an automobile lightweight will be additionally extensive.
The development and popularization of new energy vehicles (E-Vehicles) advance the market for composite materials in lightweight automobiles. With the market enlargement, using composite materials for lightweight vehicle structures will be a concern for manufacturers.

## 7. Future Scope

The present research work demonstrates that, the jute and okra fiber-reinforced composites have encouraging potential for usage in automobile bumper beam applications, but further research is necessary to fully exploit their industrial and economic potential. Further research and development can increase the use of this potential materials in the automobile industry and other sectors, improve performance, and address current limitations.

1. **Advanced Mechanical Assessment**

   Further studies can look at dynamic impact, and crashworthiness examination of the produced composites in real-world automotive environments to verify long-term durability.

2. **Hybrid Natural Fibre Combinations**

   The mechanical and thermal properties of the composite could be enhanced by hybridising jute and okra with other natural fibres like sisal, flax, banana or hemp.

3. **Industrial manufacturing and process scale-up**

   Scalability for integration into existing automobile assembly lines and high-volume production utilising injection or compression moulding processes is being investigated in the context of industrial manufacturing and process scale-up.

4. **Checking for Standardisation and Compliance**

   By carrying out thorough conformity testing with international automotive standards (such FMVSS, ECE, and ISO), it can be easier to get OEM certification.

## 8. PUBLICATIONS

**Research Paper Publication:** 2 SCI, 2 Scopus, and 2 Non-Scopus.
**Conference Paper Presentation:** 1 International and 2 National.

| Sr. No. | Publications Details |
|---|---|
| 1 | **Title:** Eco-sustainable bio-composite material<br>**Name of Journal:** Man-made Textiles in India<br>**Type of Journal:** Scopus<br>**Status:** Published, Vol. 48(11), 2020, 373-378.<br>**DOI:** NA<br>**Authors:** Prafull P. Kolte, Dr. Vijay S. Shivankar, Dr.P.P.Raichurkar |
| 2 | **Title:** The Potential of Abelmoschus Esculentus Fiber<br>**Name of Journal:** Journal of the Textile Association<br>**Type of Journal:** Scopus<br>**Status:** Published, Vol. 83(6), 2023, 420-423.<br>**DOI:** https://doi.org/10.56716/4/1489<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 3 | **Title:** Characteristics of Abelmoschus Esculentus (Indian Okra) Fiber Varieties<br>**Name of Journal:** ICE- Emerging Materials Research<br>**Type of Journal:** SCI (IF: 1.795)<br>**Status:** Published, Vol. 12(2), June 2023, 204-211.<br>**DOI:** https://doi.org/10.1680/jemmr.22.00230<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 4 | **Title:** Some Studies on Abelmoschus Esculentus (Indian Okra) Fiber Characteristics<br>**Name of Journal:** Journal of Materials Science: Materials in Engineering<br>**Type of Journal:** SCI [IF 3.4]<br>**Status:** Published Vol. 19:39, (2024), 1-10.<br>**DOI:** https://doi.org/10.1186/s40712-024-00188-2<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 5 | **Title:** Renewable Composite Material for Automotive Application<br>**Name of Journal:** Asian Technical Textiles<br>**Type of Journal:** Non-Scopus International Journal<br>**Status:** Published Vol. 14(4), October-December 2020, 33-36.<br>**DOI:** NA<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 6 | **Title:** Renewable Composite Material: A Composite for 21st Century<br>**Name of Journal:** National Level Conference TEXCON 2020<br>**Type of Journal:** Non-Scopus<br>**Status:** Published in conference proceeding at pp.153-158, 2023.<br>**DOI:** NA<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |

| | |
|---|---|
| | **Presentations Details** |
| 1 | **Title:** Renewable Composite Material: A Composite for 21st Century<br>**Name of Conference:** Conference TEXCON 2020 Organised by SVVV, Indore<br>**Type of Conference:** National Level<br>**Status:** Presented on 3rd Oct 2020.<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 2 | **Title:** Environmental Friendly Composite Material for Automotives<br>**Name of Conference**: Futururistics Trends in Textile 2020-21.<br>**Type of Conference:** National Level<br>**Status:** Presented on 26th March 2021.<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |
| 3 | **Title:** Characteristics of Abelmoschus Esculentus Fiber Varieties<br>**Name of Conference:** Digital Technology Vision 2030: Transforming Healthcare, Education and Industry (ICDTV: 2030)<br>**Type of Conference:** International Level Conference<br>**Status:** Presented on 17th February 2024.<br>**Authors:** Prafull P. Kolte & Dr. Vijay S. Shivankar |

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